Direct radiative effect of intense dust outbreaks in the Mediterranean

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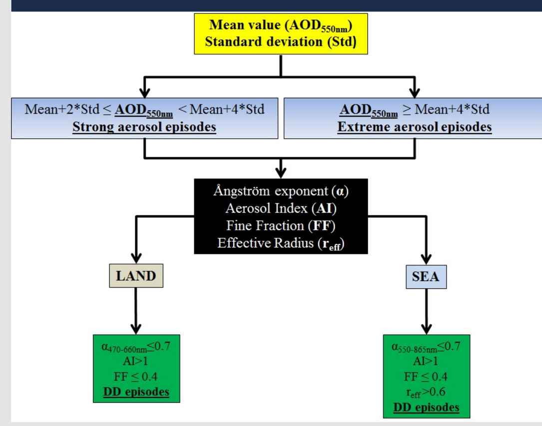
Aim of the study - Methodology

This study aims at describing, through NMMB/BSC-Dust model simulations, the impact of three consecutive dust outbreaks, that took place from 9/4 to 15/4/2008, on the radiation budget of the broader Mediterranean area. First, the desert dust (DD) episodes are identified at a pixel level (1°x1°) and on daily basis, over the period 2000-2013, using an objective and dynamic algorithm (flowchart), which utilizes various daily satellite retrievals as inputs. Then, are kept only the days where at least 30 pixels (Gkikas et al., 2015) have undergone a DD episode. From these days, it is found the longest period of consecutive days characterized by widespread DD episodes. According to this methodology, the period extending from 9th to 15th April 2008 is selected and studied here.

Identification of desert dust outbreaks

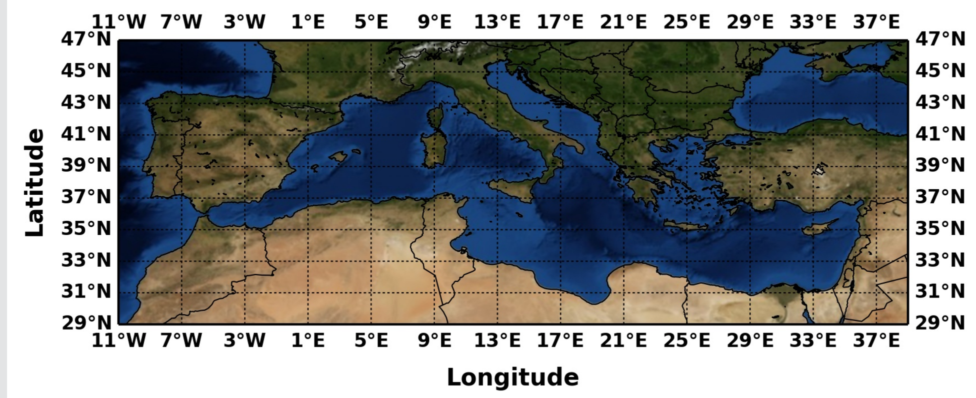


Study period: 1 March 2000 - 28 February 2013
Studied case: 9-15 April 2008
Satellite domain: 11° W - 39° E, 29° N - 47° N
Satellite sensors: MODIS-Terra (C051), EP - TOMS, OMI - Aura
Temporal resolution: Daily retrievals
Spatial resolution: 1° x 1°

MODIS-Terra
- AOD at 550nm (Land and Sea)
- Ångström exponent (Land and Sea)
- Fine Fraction (Land and Sea)
- Effective radius (Sea)

EP-TOMS & OMI-Aura
- Aerosol Index (Land and Sea)

Satellite domain



NMMB/BSC-Dust Model

- NMMB/BSC-Dust model contains a dust module embedded online within the NCEP Non-hydrostatic Multiscale Model (NMMB).
- Provides weather and dust forecasts, from regional to global scales, thanks to its unified non-hydrostatic dynamical core.
- Dust cycle is represented through several parameterizations describing dust particles' sources, emissions, transport, removal from the atmosphere (wet and dry deposition) as well as the interaction with the radiation (Pérez et al., 2011).
- After a 10-day spin-up period, a forecast period of 168 hours starts at 00:00 UTC of 9th April 2008.
- NCEP final analyses (FNL) initial and boundary conditions at 1°x1° are used.
- The simulation domain covers the largest part of Europe as well as the northern African and Arabian Peninsula deserts, at 0.25°x0.25° spatial resolution and for 40 hybrid sigma pressure levels up to 50hPa.

Direct Radiative Effect

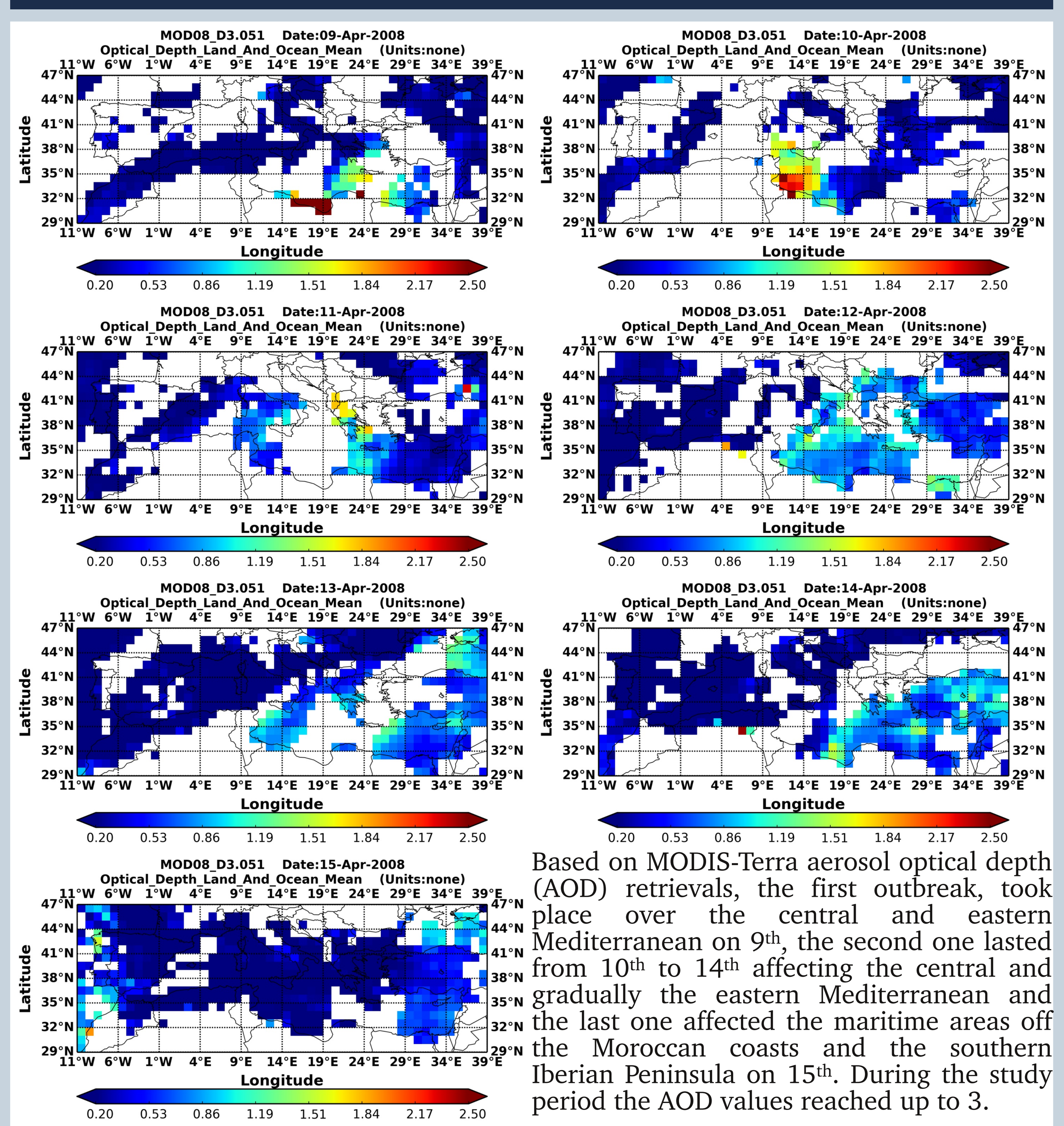
The direct radiative effects (DREs) of aerosols are calculated based on the following formulas:

1. Top of Atmosphere (**TOA**) $DRE_{TOA} = F^{\uparrow}_{TOA,RADOFF} - F^{\uparrow}_{TOA,RADON}$
2. Into the Atmosphere (**ATMAB**) $DRE_{ATMAB} = F_{ATMAB,RADON} - F_{ATMAB,RADOFF}$
3. Downwelling radiation at surface (**SURF**) $DRE_{SURF} = F^{\downarrow}_{SURF,RADON} - F^{\downarrow}_{SURF,RADOFF}$
4. Absorbed radiation at surface (**NETSURF**) $DRE_{NETSURF} = F_{NETSURF,RADON} - F_{NETSURF,RADOFF}$

RADON: dust-radiation interaction | **RADOFF:** no dust-radiation interaction

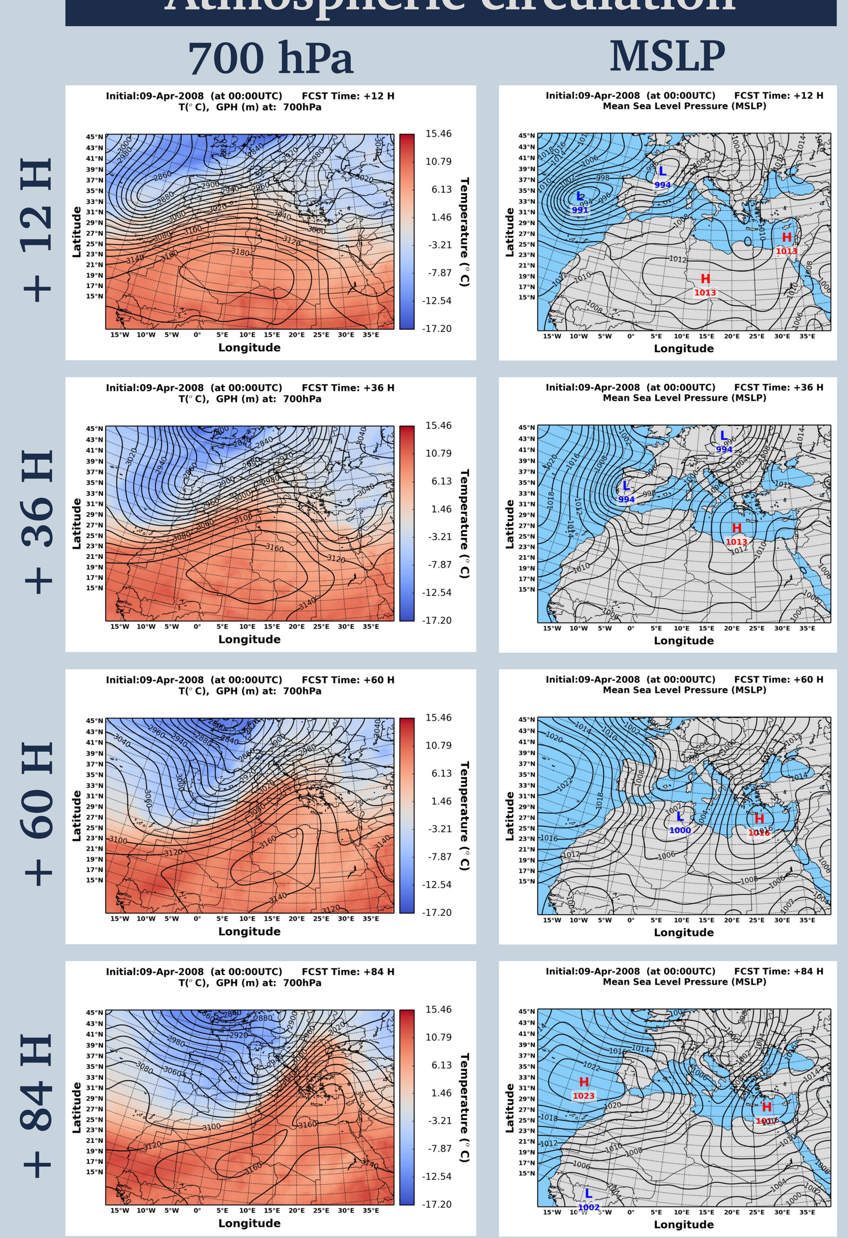
Positive DREs indicate warming while negative DREs indicate cooling.

Satellite observations

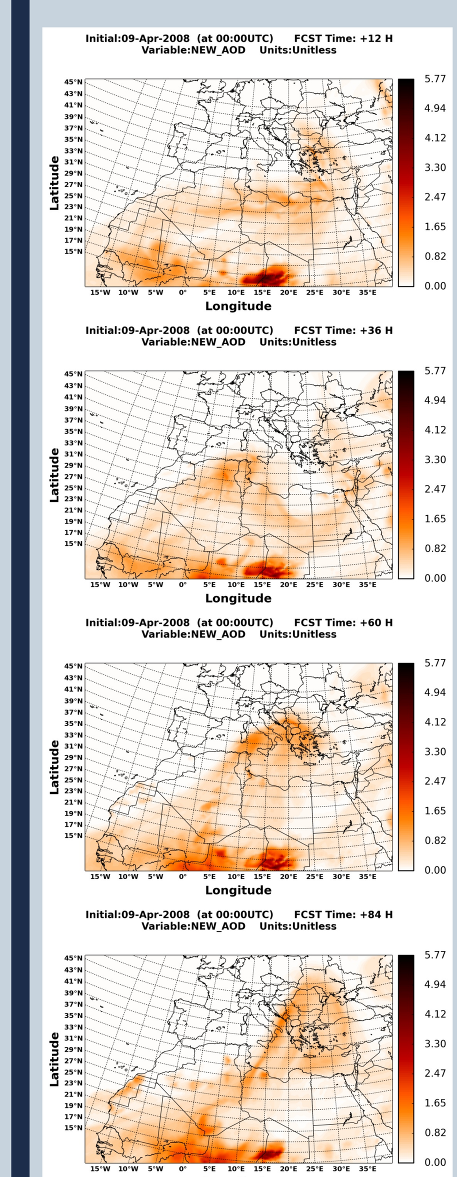


Based on MODIS-Terra aerosol optical depth (AOD) retrievals, the first outbreak, took place over the central and eastern Mediterranean on 9th, the second one lasted from 10th to 14th affecting the central and gradually the eastern Mediterranean and the last one affected the maritime areas off the Moroccan coasts and the southern Iberian Peninsula on 15th. During the study period the AOD values reached up to 3.

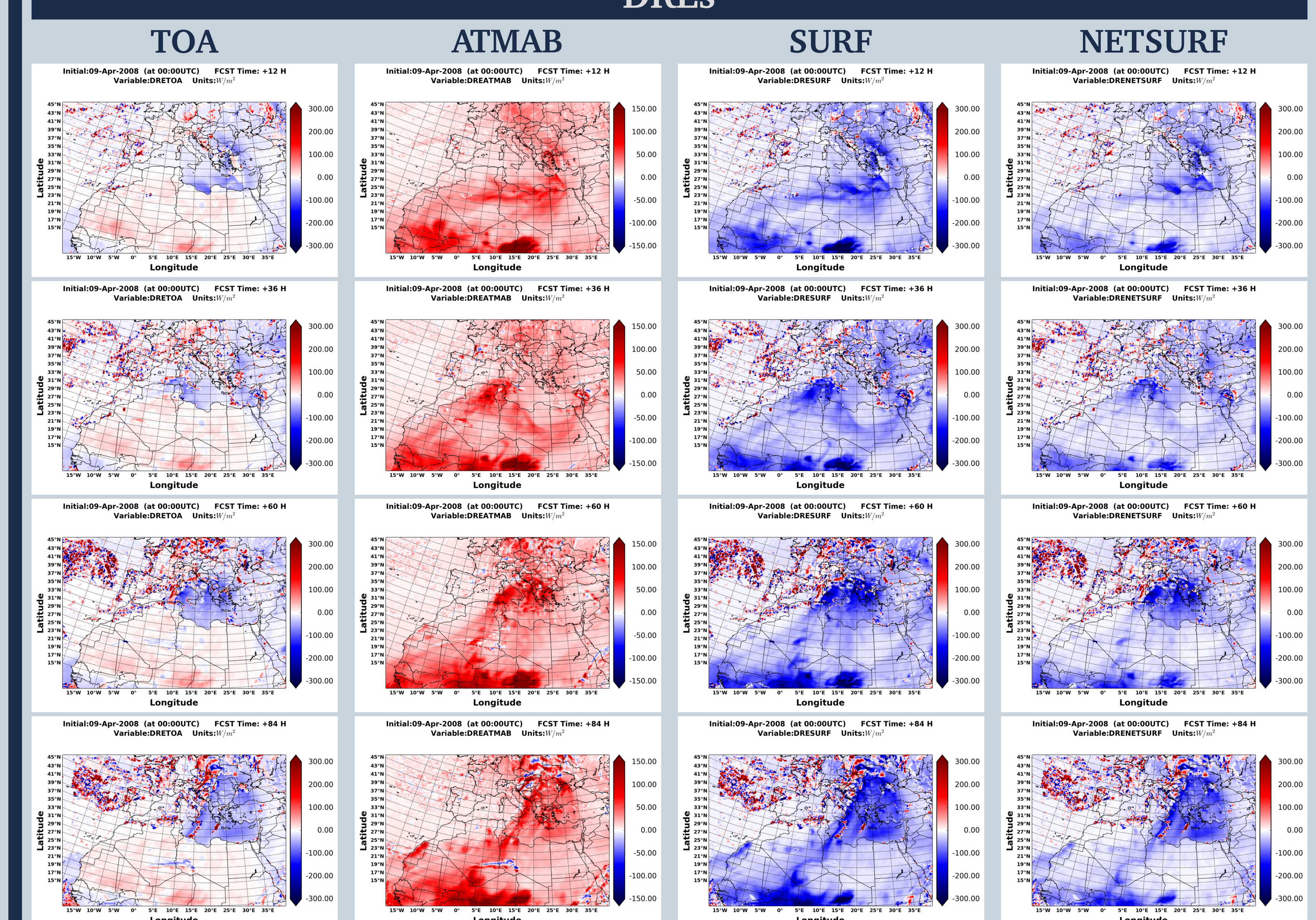
Atmospheric circulation



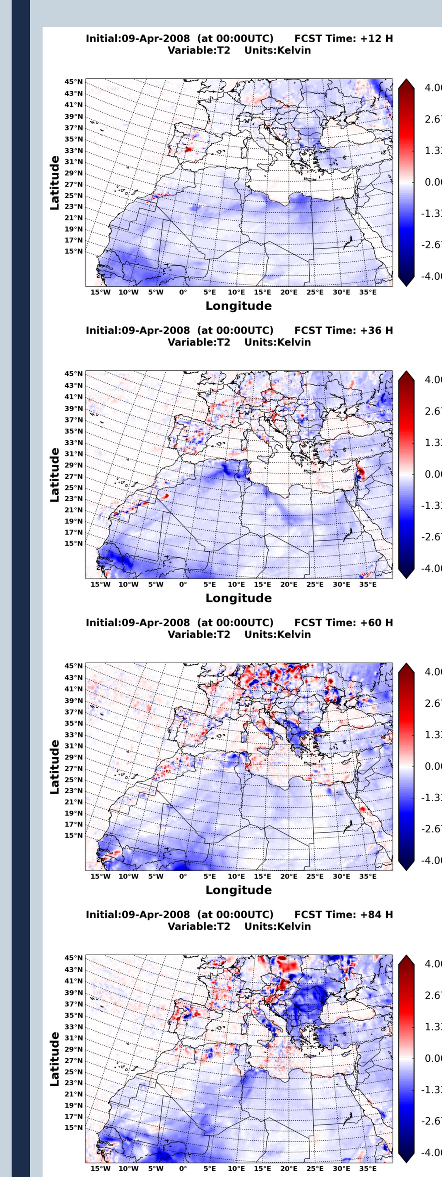
Dust AOD



DREs



Temperature 2m



Atmospheric circulation - Dust AOD

At +12h, a low pressure system, centered in the northwestern Atlantic Ocean, in combination with prevailing anticyclonic conditions across the Sahara, induces a strong southwesterly and westerly airflow, at 700hPa, over the western and eastern Mediterranean, respectively. The barometric low shifts over the Iberian Peninsula (+36h) and Algeria (+60h) while the anticyclone over the eastern Mediterranean is reinforced for increasing forecast hours. At 700hPa, gradually intensifying strong southwesterly winds blow over the central Mediterranean leading to significant dust transport through to the northern Balkans (+84h).

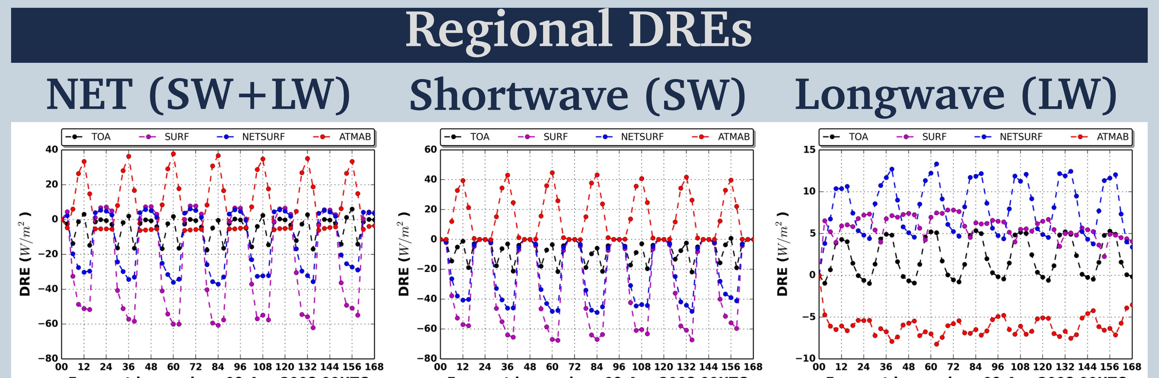
Direct radiative effect

The instantaneous NET (SW+LW) DREs' patterns are driven by the corresponding ones of dust AOD. At TOA, negative DREs, down to -150Wm^{-2}, are found in the central and eastern Mediterranean while positive values (up to 50Wm^{-2}) are obtained in the Sahara, indicating planetary cooling and warming, respectively. In the dust affected areas, DRE_{ATMAB} values can reach up to 150Wm^{-2} indicating a strong atmospheric warming. On the contrary, the downwelling (SURF) and absorbed (NETSURF) radiation at surface are reduced by up to 300Wm^{-2} resulting thus to a strong surface cooling.

Temperature at 2 meters

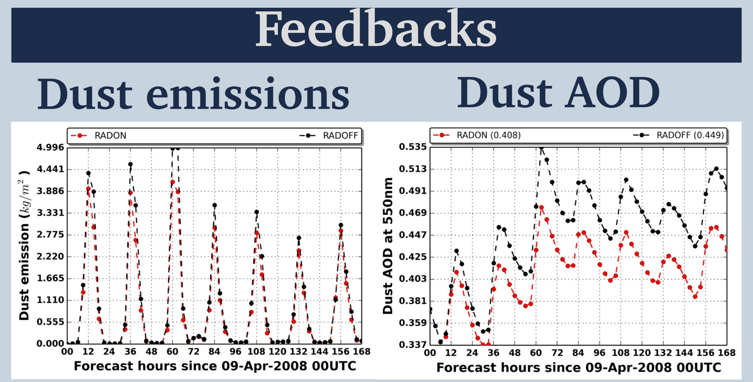
Based on model simulations, the temperature at 2 meters can be decreased by up to 4°C during daytime while an increase of 2.5°C is found during nighttime (not shown here). The former impact is attributed to dust aerosols' interaction with the incoming solar (scattering and absorption) and the latter one to their interaction with the outgoing terrestrial (absorption and re-emission) radiation. These reverse temperature tendencies lead to a reduction of the diurnal temperature range in the dust affected areas.

Regional DREs



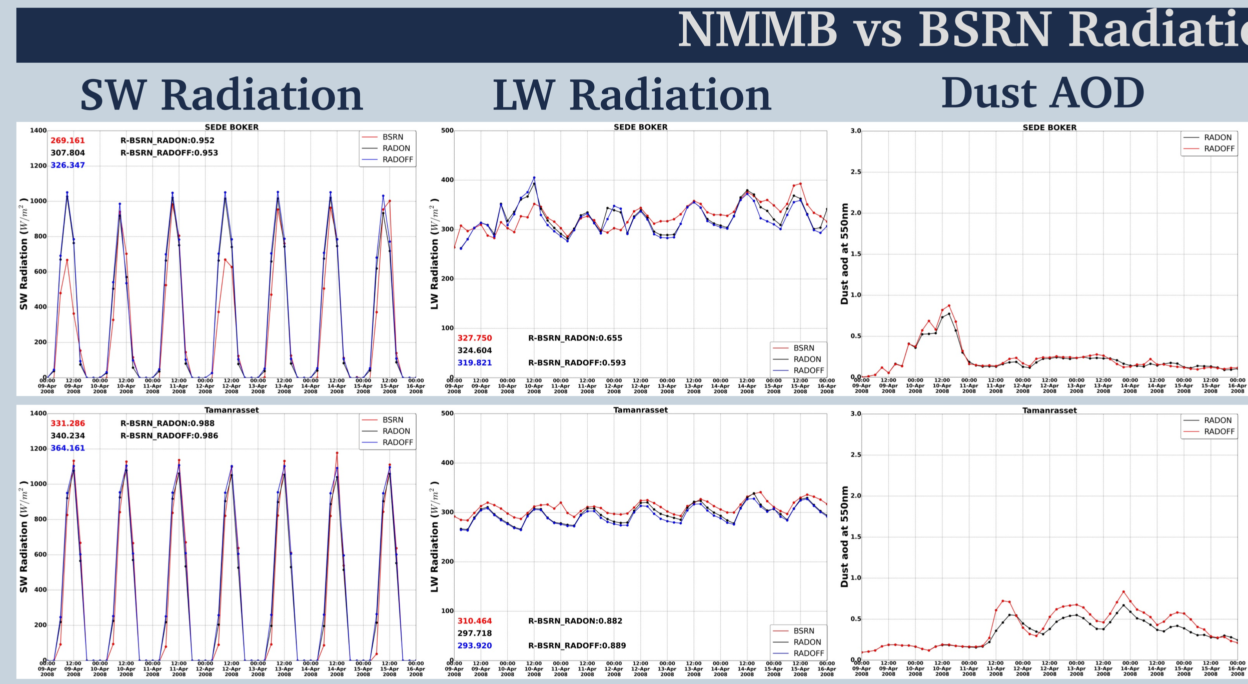
The averaged regional DREs have been obtained for the whole simulation domain, under clear-sky conditions, for the NET, SW and LW radiation. Based on our results, into the atmosphere, the positive NET DRE_{ATMAB} values (warming effect) are maximized (40Wm^{-2}) at noon while slightly negative values (-10Wm^{-2}) are recorded during night. On the contrary, DRE_{SURF} and $DRE_{NETSURF}$ values are negative (cooling effect) down to -60Wm^{-2} and -40Wm^{-2}, respectively, around noon, becoming slightly positive (10Wm^{-2}) at night. In general, DRE_{TOA} values are negative (down to -20Wm^{-2}) being overturned to positive at noon. NET DREs are dominated by the SW impacts compared to the LW ones. Reverse effects, of smaller magnitude, are found for the LW DREs compared to the SW ones.

Feedbacks



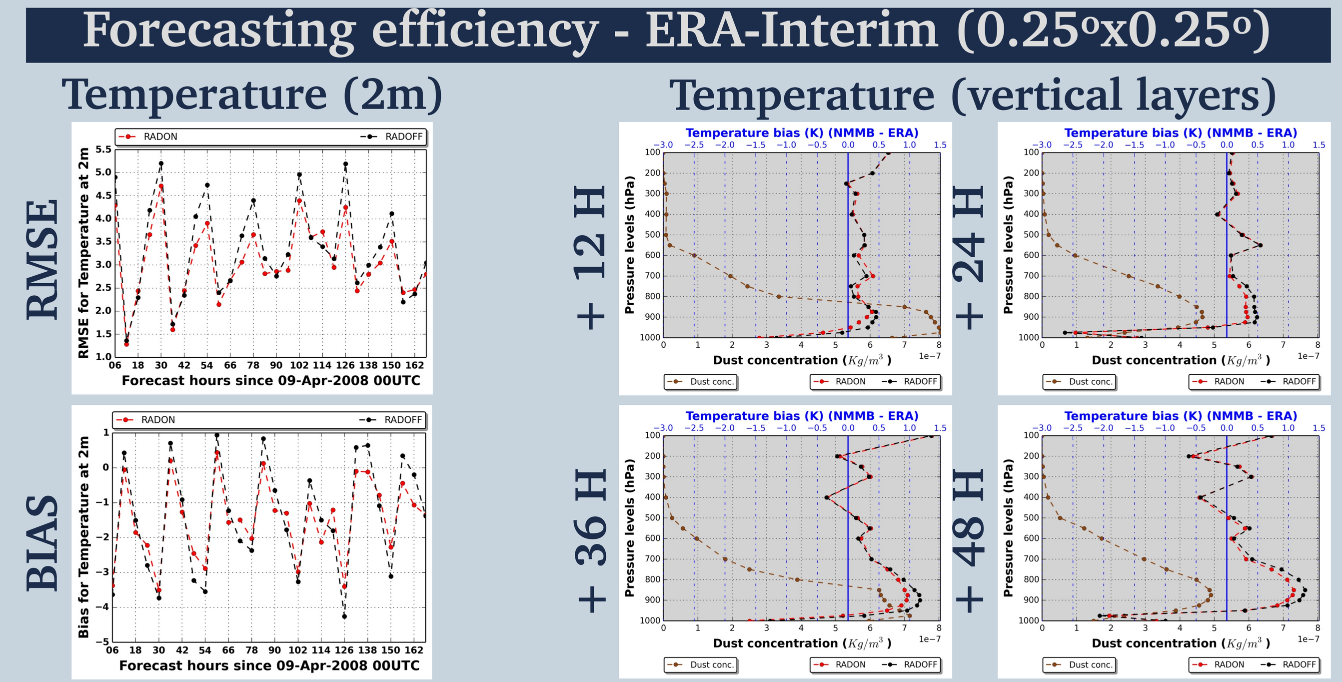
During the study period, the total emitted amount of dust is reduced by 17% for the RADON compared to the RADOFF simulation. The emission rates reduction is more pronounced at noon. Due to less emitted dust amount into the atmosphere the dust aerosol optical depth is decreased by 9%. Both results indicate a negative feedback of dust outbreaks on dust emissions and optical depth when dust radiative effects are included in the numerical simulation.

NMMB vs BSRN Radiation



The NMMB outputs of the SW and LW downwelling radiation at the ground have been evaluated against BSRN (Baseline Surface Radiation Network) measurements at Sede Boker (Israel) and Tamanrasset (Algeria), which have been affected by dust loads, based on model simulations, on 10th and from 11th to 15th, respectively. The model's performance is better for the SW (R>0.95) than for the LW (R>0.59) radiation, in both stations. Between the two model configurations (RADON and RADOFF), there are not evident differences in terms of correlation coefficients. Nevertheless, the biases between model outputs and ground observations are lower in the RADON regards to the RADOFF simulation. The maximum negative differences between NMMB and BSRN SW radiation, which are recorded on 9th and 12th in Sede Boker, are possibly attributed to the inability of the model to reproduce accurately the clouds.

Forecasting efficiency - ERA-Interim (0.25°x0.25°)



In the present section, it is investigated what is the impact on forecast temperature at 2m, as well as for 18 pressure levels, when dust radiative effects are considered in the numerical simulations. As reference data, the ERA-Interim reanalyses, provided at 0.25°x0.25° spatial resolution, are utilized. In both comparisons are considered only the grid points where dust AOD from the RADON simulation is higher/equal than 0.5. A second criterion is applied for the comparison of temperature at 2m by masking out the "sea" grid points. According to our analysis, when dust-radiation interaction is activated it is apparent a reduction, particularly during nighttime, of the BIAS and RMSE scores revealing thus a better agreement between NMMB and ERA. In vertical terms, the positive NMMB-ERA differences, between 950 and 500hPa, are reduced by up to 0.3°C for the RADON (red curve, upper x-axis) with respect to the RADOFF (black curve, upper x-axis) simulation. These improvements are more remarkable slightly above the maximun dust concentrations at noon (brown curve, bottom x-axis) and at the same pressure level at night.

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Pérez et al. (2011): Atmospheric dust modeling from meso to global scales with the online NMMB/BSC-Dust model – Part 1: Model description, annual simulations and evaluation, Atmos. Chem. Phys., 11, 13001-13027, doi:10.5194/acp-11-13001-2011.

Conclusions

- Study of the direct radiative effects, through NMMB/BSC-Dust simulations, induced by three Mediterranean dust outbreaks, which took place from 9th to 15th April 2008.
- Strong atmospheric warming (up to 150Wm^{-2}) and surface cooling (down to -300Wm^{-2}) in the dust affected areas.
- At TOA, negative (down to -150Wm^{-2}) and slightly positive (up to 50Wm^{-2}) instantaneous DREs are recorded in the Mediterranean and the Sahara, respectively.
- Reverse LW effects, of smaller magnitude, compared to the SW ones.
- At a local scale, temperature at 2m is decreased by up 4°C during daytime while an increase of 2.5°C is found during nighttime.
- Dust outbreaks induce a negative feedback on dust emissions and AOD.
- Bias reduction between NMMB and BSRN for the SW and LW downwelling radiation at the surface for the RADON simulation.
- Improvement of forecast temperature at 2m, particularly during nighttime, when dust radiative effects are included in the simulation.
- Better agreement between NMMB and ERA temperature profiles when the dust-radiation interaction is activated (RADON simulation).